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Title: Effects of Visual Communication Tool and Separable Status Display on Team Performance and Subjective Workload in Air Battle Management

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14. ABSTRACT

Tactical Air Battle Managers, such as AWACS Weapons Directors (WDs), perform as a team to effect command and control (C2) of assigned forces by planning, organizing, and directing operations. Specifically, AWACS WDs must coordinate offensive counter-air, defensive counter-air, and air refueling operations. AWACS WD teams accomplish their C2 function through networked collaboration that is typically supported by monitoring multiple radio communications channels under conditions of moderate to high ambient cabin noise while performing several visual and manual tasks. The purpose of this study is to compare team performance and subjective workload on a simulated AWACS scenario, for two conditions of communication (Voice-only, and Voice augmented with a Visual Communication Tool), and using two supplementary display conditions (Separable Status Display and No-Separable Status Display). Team performance measures on the AWACS scenario include 1) the percentage of enemy targets that were allowed to penetrate friendly airspace, 2) the percentage of high value assets destroyed (i.e., the air base, infantry units, and tanker aircraft), 3) the percentage of fighter assets that were lost due to fuel depletion or enemy attack, 4) the average time of enemy target prosecution.

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Abstract

Tactical Air Battle Managers, such as AWACS Weapons Directors (WDs), perform as a team to effect command and control (C2) of assigned forces by planning, organizing, and directing operations. Specifically, AWACS WDs must coordinate offensive counter-air, defensive counter-air, and air refueling operations. AWACS WD teams accomplish their C2 function through networked collaboration that is typically supported by monitoring multiple radio communications channels under conditions of moderate to high ambient cabin noise while performing several visual and manual tasks. The purpose of this study is to compare team performance and subjective workload on a simulated AWACS scenario, for two conditions of communication (Voice-only, and Voice augmented with a Visual Communication Tool), and using two supplementary display conditions (Separable Status Display and No-Separable Status Display). Team performance measures on the AWACS scenario include 1) the percentage of enemy targets that were allowed to penetrate friendly airspace, 2) the percentage of high value assets destroyed (i.e., the air base, infantry units, and tanker aircraft), 3) the percentage of fighter assets that were lost due to fuel depletion or enemy attack, 4) the average time of enemy target prosecution.

Introduction

Air Battle Managers (ABMs) effect command and control (C2) of assigned forces by planning, organizing, and directing operations. Specifically, ABMs provide friendly forces with a 'big picture' of the battle-space; assisting combat aircraft in finding, identifying, and destroying enemy targets, keeping track of friendly assets, and coordinating air refueling.

Air battle management functions are accomplished at the operational level through Air Operations Centers (AOC) and at the tactical level through the USAF E-3 Airborne Warning and Control System (AWACS), the E-8 Joint Surveillance Target Attack Radar (JSTARS), the USN E2C Hawkeye (see Armistead [2002] and Williams [1997] for more information on airborne platforms), and a variety of ground-based Control and Reporting Centers (CRC). At the tactical level, functionality is contingent upon sensor capabilities: AWACS and JSTARS' radar and computer subsystems can gather and present expansive and detailed battle-space information for air-to-air and air-to-surface battle management; USN E2C Hawkeye is a carrier-based system with similar air-to-surface and air-to-air sensor capability for maritime tactical scenarios; and CRCs are land based, short-range systems responsible for tactical air control within their area of responsibility (AOR).

Despite the variety of battle management platforms, Weapons Directors (WDs; i.e., Air Battle Managers) perform analogous tasks, under similar conditions, with comparable displays and controls (Knott et al., 2007). Thus WDs are required to monitor a multiplicity of simultaneous communications channels under conditions of moderate to high ambient cabin noise while performing several visual and manual tasks (Bolia et al., 2005). Additionally, said tasks are performed as part of an integrated team or team of teams. The latter requirement is significant because it emphasizes the importance of collaboration for the achievement of tactical and operational goals (Knott et al., 2006).

Currently, WDs collaborate (i.e., monitor and transmit) through several, often overloaded voice communication channels, within a field of moderate to high ambient platform noise (Bolia et al., 2005). Thus alternative forms of communication such as visual communication could mitigate the above issues and provide a meaningful platform for collaboration. Indeed, language (i.e., spoken and written) is only one type of communication among other types of sign systems that can be learned, transmitted, and interpreted. However, it is unknown as to how the employment of non-language based communication systems utilized in conjunction with language-based systems affects team performance. Specifically, for the air battle management domain, determining whether non-language based communication modalities reduce the demands of a saturated voice channel can contribute to the development of more effective collaborative systems. In other words, an understanding of the relative demands (e.g., information) of various communication modalities (e.g., visual and language-based) can reveal the potential advantages and disadvantages of utilizing different communication modalities in conjunction.

Contemporary semioticians study signs (i.e., "…something which stands to somebody for something in some respect or capacity"; Peirce, 1931) as part of meaningful semiotic 'sign systems'. According to semiotics, meaningful communication can be transmitted through any medium or text (i.e., a message or assemblage of signs that has been recorded in some way), including verbal, non-verbal, or both. Additionally, semioticians maintain that the multi-sensory

nature of human experience renders every representation of experience subject to the constraints of media involved. Thus, for example, the flexible medium of radio communication provides a transient signal that can easily be missed, misinterpreted, or forgotten. Furthermore, the communication ‘signal’ transmitted by a particular medium can face ‘interference’ by various forms of extrinsic ‘noise’. Consequently, for example, the meaning of communication over radio channels can be lost through a field of background ambient noise.

Communicating meaningful information is a key component of *net-centricity*. Net-centricity is defined as the “ability to get the right information to the right people, at the right time, using the right media, in the right language and at the right level of detail” (Satellite Evolution Global, 2006). Net-centricity requires appropriate collaborative systems to afford users the ability to discover, access, and integrate information that supports mission objectives. In a net-centric environment, WDs will have more information at their fingertips from remote sensors. However, with regard to WD effectiveness, the relative effects of increased information availability have not been determined. Thus, it is unknown as to whether the provision of more system-related information will reduce the need for communication (e.g., language-based or visual); increase/decreased perceived workload; or increase/decrease mission-related performance.

The current literature on collaboration technologies and computer-mediated communication focuses almost exclusively on language-based or verbal communication paradigms within business environments with the goal of achieving common work products, such as decision consensus (Knott et al., 2007). Thus, the applicability of these studies to military C2 domains, where the task is to execute a mission, is limited. The purpose of the present investigation is to compare the performance of teams using radio voice communication with teams utilizing 1) a near real-time iconographic digital whiteboard interface and 2) a separable digital interface that displays low-level, but pertinent information (i.e., fuel and weapons status) as a supplementary means of communication in a high-workload military C2 environment.

Method

The DDD Simulator

The Distributed Dynamic Decision-Making (DDD; see www.Aptima.com) software is a tool for creating human-in-the-loop, distributed, multi-person simulations. The DDD was employed to create a set of Tactical Air Battle Management TABM simulations conveyed to participants through a tactical display.

Scenarios

A set of tactical air battle management (TABM) scenarios were developed for this experiment and are designed to require a team of two Weapons Directors (WDs) to coordinate to sustain offensive counter-air, defensive counter-air, and air refueling operations. Weapons Directors coordinate operations (i.e., intercept threats and re-supply assets as needed) through communication, sharing of fighter assets, and allocating two tanker assets. The scenarios were presented to WDs via the DDD tactical display (see Figure 1), which represented the area of operations with friendly assets and enemy targets shown as unique symbols. The tactical display afforded a real-time representation of the battle space from which WDs were able to monitor and direct simulated air operations.

The tactical display divides the area of operations into three regions – Gray, Yellow and Red zones – that represent different operational areas. The Gray zone is the 'kill zone', the Yellow zone represents friendly airspace, and the Red zone represents the friendly region containing ground assets (i.e., Ranger units and an air base). The green and blue symbols represent friendly fighter assets that are labeled according to their platform type (e.g., F-18) and callsign (e.g., Shaggy). Additionally, there are two tanker aircraft (i.e., Air Force and Navy) for aerial refueling of designated fighter assets. Thus, the Air Force tanker is 'equipped' to refuel F-15s and F-16s and the Navy tanker is 'equipped' to refuel F-18s.

The scenario is a 10-minute simulated counter air operation in which enemy targets enter the green zone and immediately begin moving towards friendly territory. Enemy forces have the ability to attack and destroy all fighter assets, tankers, the air base and the infantry.

Each fighter begins the scenario with weapons resources adequate to complete two attacks on hostile targets (F15/F16/F18s can eliminate MiGs; only F18s can eliminate Su27s), and with a randomly assigned quantity of fuel. The WD's task is to choose appropriate asset-target pairings given the available resources for each asset, communicate the asset-target pairing decisions to friendly fighter assets, and prioritize and coordinate weapons re-supply and aerial refuelling with the tankers.

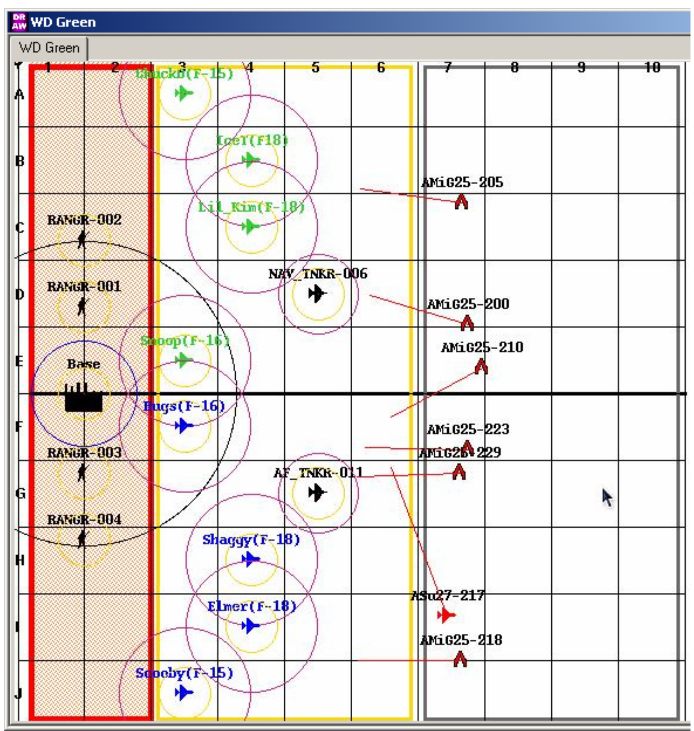

Figure 1. The WD's tactical situation display. The Green and Blue WD assets are colour-coded and labelled with a call-sign. The blue and yellow rings represent a fighter asset's sensor range and vulnerability to attack, respectively. The enemy targets, labelled as MiG-25s or Su-27s, enter the simulation from the right of the display.

Each WD is assigned a separate geographic region within the area of responsibility and allocated fighter assets to manage. The area of responsibility is divided into two prescribed

regions, a northern (WD Green's region) and a southern (WD Blue's region), and their division was indicated on the tactical display by a solid black horizontal line. Additionally, asset symbols were color-coded to represent asset allocation and control (e.g., green assets were allocated to WD Green). Although each WD's fighters operate primarily within his or her region, fighter assets were able to cross regional boundaries if necessary to provide assistance by engaging a target for which the other WD's assets had insufficient resources.

The WDs' primary responsibilities include relaying tactical information to their assets, directing assets to intercept hostile targets, and coordinating aerial re-supply between assets and tankers. To do this effectively, WDs must understand the capabilities and limitations of their operational environment. Within the simulation, all friendly fighter assets had the same fuel capacity. However, at the onset of each mission scenario, each asset was randomly assigned different fuel loads. Thus, each fighter asset had to be refuelled once during the 10-minute scenario. All assets have weaponry adequate for two attacks before they must be re-supplied. Enemy targets were differentiated by their on-screen representation and their speed of movement. The majority of enemy targets in each scenario were represented by a red, inverted "V." These targets, identified as "MiGs," were slightly slower than WD fighter assets and could be pursued and intercepted from behind. The second type of enemy target, identified as "Su-27s," was represented by a red fighter symbol. Such targets were slightly faster than WD fighter assets, rendering pursuit ineffectual, and therefore required frontal interception by fighter assets. Each time a MiG was intercepted and destroyed, a new one would enter the airspace to replace it from the right side of the display. Thus, the number of targets present throughout scenario was deliberately controlled.

The WDs in this scenario are members of multiple teams. The WDs communicate directives to friendly assets through Strike Operators (Green Strike and Blue Strike) and a Tanker Operator. The two Strike Operators play the role of multiple fighter pilots and manoeuvre assets via the DDD interface as directed by their WD. The Tanker Operator manoeuvres the two tankers (an Air Force Tanker and a Navy Tanker) to refuel and resupply assets as directed by the WDs. In this experiment, Strike and Tanker Operators were highly practiced confederates trained to expertise in the role of the strike fighter and tanker operators. As such, their performance is related to, but is not the focus of, team performance in this experiment. Instead, the primary focus is the WDs' task performance.

The team in this scenario included five individuals: Green WD, Blue WD, Green Strike, Blue Strike and the Tanker Operator. The two WDs have all decision making responsibility and direct and manage all air combat operations, coordinate the team, and act on information gleaned from their tactical display and from communication with the other operators. The Tanker Operator and Strike Operators, on the other hand, execute directives from the WDs and also, depending on experimental condition, provide the WDs with status updates on their assets, such as fuel and weapons levels.

The WDs' tactical displays provide a global picture of the simulated battle space, including all allied and enemy entities. The Strike Operators are able to see all friendly air or ground assets, but see enemy aircraft only when they come within the limited range of their platform's sensors (represented by a blue ring). Thus, they have limited awareness of the tactical picture and must rely on the WDs to vector them to targets.

The experiment took place in a 9.75 m × 6.5 m room with two WDs on one side of the room and the Strike and Tanker Operators on the other side, facing the opposite direction. Each operator had a 17-inch flat-panel display that presented the tactical display, the Virtual Whiteboard tool for visual communication, and the Separable Status Display (i.e., provides fuel and weapons status for fighter assets). ModIOS® Voice Communicator was used for simulated network radio communication. Each of the WD's radios comprised one communication frequency for speaking with their Strike Operator, the Tanker Operator, and their WD partner. The Virtual Whiteboard tool provided a transparent overlay that facilitated visual communication between WDs and their Strike Operators and Tanker Operator.

The Virtual Whiteboard is a domain-specific graphical collaboration tool tailored specifically to the needs of prescribed task (e.g., Bolstad & Endsley 2005). It was developed to augment linguistic communication in the air battle management domain. The Virtual Whiteboard affords near real-time conveyance of tactical display and iconographic information (i.e., task-relevant symbols indicating desired actions or directives) between WDs.

WDs used the DDD tactical display to monitor the battle and then used the communications software to issue directives to the Strike and Tanker Operators. The Strike Operators and Tanker Operators used the DDD interface to operate the strike assets and tankers and to retrieve information about their assets. Radios were operated with a footswitch for all operators. Participants wore headsets throughout the experiment and white-noise was generated in the lab at approximately 75 dBA during all trials. The purpose of the white-noise was to simulate the noise of an AWACS or JSTARS platform, and to prevent participants from communicating with each other except by the means provided.

Secondary task. The Coordinate Response Measure (CRM; Bolia et al., 2000) consists of 2,048 unique phrases of the form "Ready (CALL SIGN), go to (COLOR) (NUMBER) now," for example "Ready Baron, go to White Four now". Eight unique voices – four male and four female- read each of 256 possible Call Sign, Color, Number combinations, and each file is approximately 1.5 seconds in duration. Use of the Color/Number pair of the CRM stimuli provides a secondary task requiring participants to attend not only to identifying the voice that is speaking but also to the informational content of the message they are hearing – a quality similar to real-world interactions.

Procedure

Prior to the experiment, all participants (WDs) completed a one day, four hour training session in which they were trained on the scenario, the radio software, Virtual Whiteboard tool, Separable Status Display, and then completed eleven 10-minute practice trials of the DDD scenario. The trainer informed participants that the purpose of the study was to evaluate how teams used communication technology to work together and that they would be playing a computer game that required teamwork to meet the game's objectives. Additionally, WDs were trained on and practiced communication brevity for voice communications. Brevity training was critical to minimize irrelevant, unnecessarily lengthy and/or confusing verbal statements.

Participants were also trained on the specific objectives and rules of the mission, and were instructed that the performance of the team would be measured for each trial based on how well they met their objectives and followed the rules. Mission objectives included: destroy as many hostile aircraft as quickly as possible; do not allow hostile aircraft to enter friendly

territory; protect the Air base and the infantry from enemy attack; protect the Air Force and navy Tankers from enemy attack; and keep as many fighters airborne for as long as possible. Mission rules included: refuel aircraft at appropriate Tanker (i.e., F18s at Navy Tanker; F15s and F16s at Air Force Tanker); refuel at Air Base only if airborne refuelling is not possible; F15/F16/F18s can attack MiGs, whereas only F18s can attack Su27s; and the Green WD is responsible for defending the Northern region, whereas Blue WD is responsible for defending the Southern region. Upon completing training, WDs were administered a training quiz. Subjects were required to obtain a score of 100% on the training quiz before moving on to experimental sessions (subjects were permitted to re-take the quiz if minimal score was not obtained).

Upon completing training, WDs returned the next day for the experimental session. In this session they completed sixteen experimental trials. Each experimental trial comprised of conducting the TABM scenario for a 10-minute run. For each experimental condition, subjects were exposed to two practice trials (without the CRM secondary task) and two non-practice trials (with the CRM secondary task). During non-practice trials, subjects were required to respond (on a 8x4 grid; see above) to CRM auditory stimuli that indicated “Ready baron, (COLOR) (NUMBER)”. After each trial, participants completed several subjective instruments designed to assess mental workload and satisfaction with collaborative technologies. Participants were given one 20-minute rest period after they had completed half of the trials. All major simulation events (e.g., the occurrence and outcome of attacks, refuelling events, etc.) were recorded in data logs for later analysis. In addition, video of the all team members and all voice and chat communications were recorded.

Experimental Design

There were two levels of Communications Modality (voice-only and voice and Virtual Whiteboard tool), and two levels of status display (Separable Status Display and no-Separable Status Display). These independent variables were combined factorially yielding a 2 × 2 within-subjects design. Each team completed two 10-minute trials under the four experimental conditions. Prior to conducting the each block of two trials, teams complete two 10-minute practice trials for the relevant condition. The order of conditions was counterbalanced across trials. In the voice and voice-and-Virtual Whiteboard condition, all members of the team were given the option to communicate using voice, Virtual Whiteboard, or a combination of the two.

Subjective Measures. A modified version of the NASAS TLX (Hart & Staveland, 1987) was used to evaluate perceived task demands. In the modified version, participants were asked to estimate the workload for the team rather than rating their individual workload.

Team Performance. Measures of team performance on the TABM scenario trials were 1) the percentage of enemy targets that were allowed to penetrate friendly airspace, 2) the percentage of high value assets destroyed (i.e., the air base, infantry units, and tanker aircraft), 3) the percentage of fighter assets that were destroyed, 4) average time to prosecute a target.

Results

Team Performance

As mentioned above, several measures of team performance were assessed for each trial. There were no significant differences on the primary measures for team performance. However, analyses indicated a significant trend for communication medium $F(1, 7) = 5.45$, $p = .052$ (see

Figure 2) on the average time average time to prosecute a target. This measure was the average elapsed time (in seconds) from when an enemy target was presented on the tactical display until it was destroyed. Analyses revealed that average time of enemy prosecution was faster during the Virtual Whiteboard conditions compared to voice-only conditions (see Figure 2).

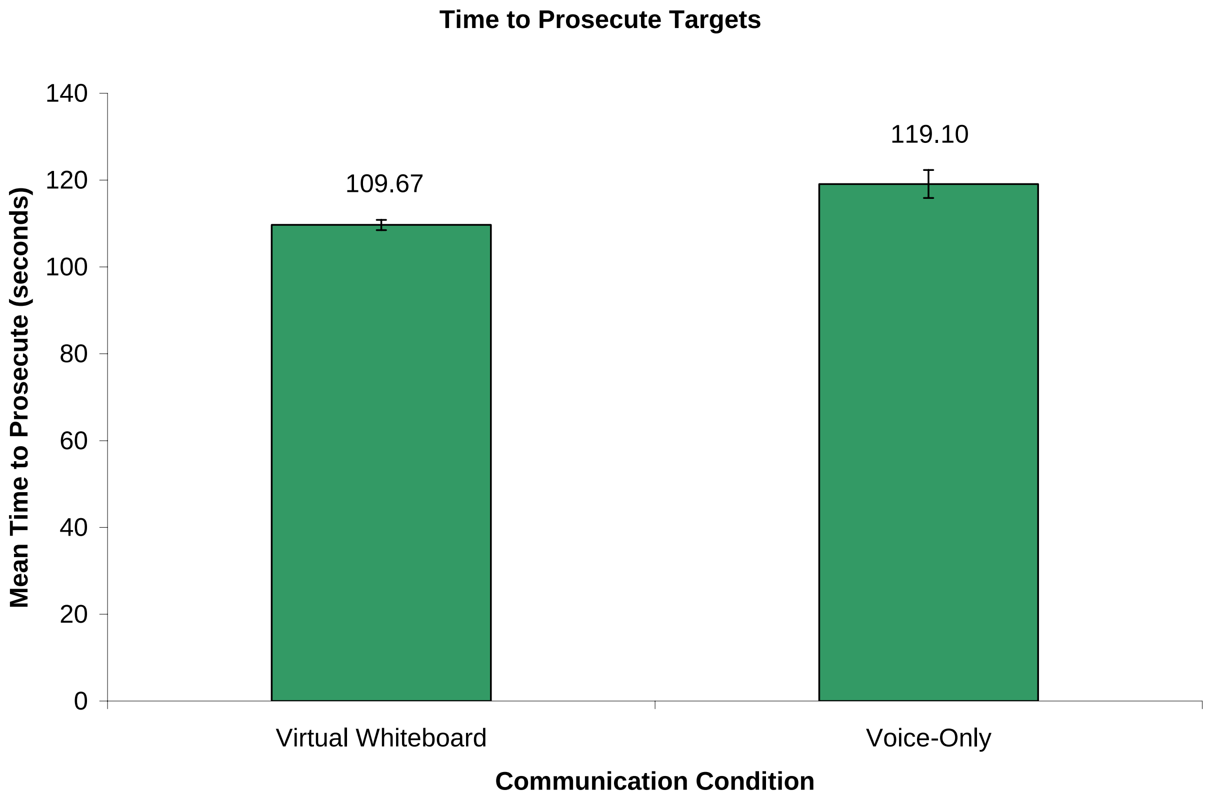

Figure 2. Mean time of enemy prosecution as a function of communication modality. Error bars represent one standard error of the mean in each direction.

Workload

As mentioned above, subjective workload (i.e., NASA-TLX) was assessed for each trial. Unweighted NASA-TLX ratings were submitted to a 5 (Subscale) × 2 (Communication Modality) × 2 (SSD) repeated measures analysis of variance. The analysis indicated a main effect for communication medium $F(1, 7) = 36.92$, $p < .001$ (see Figure 3). Also, a main effect for SSD presence was obtained, $F(1, 7) = 10.10$, $p < .05$, as (see Figure 4). Analyses revealed that mean subjective workload ratings were lowest for Virtual Whiteboard conditions and conditions without the SSD whereas mean subjective workload ratings were highest for voice-only conditions and conditions with the SSD.

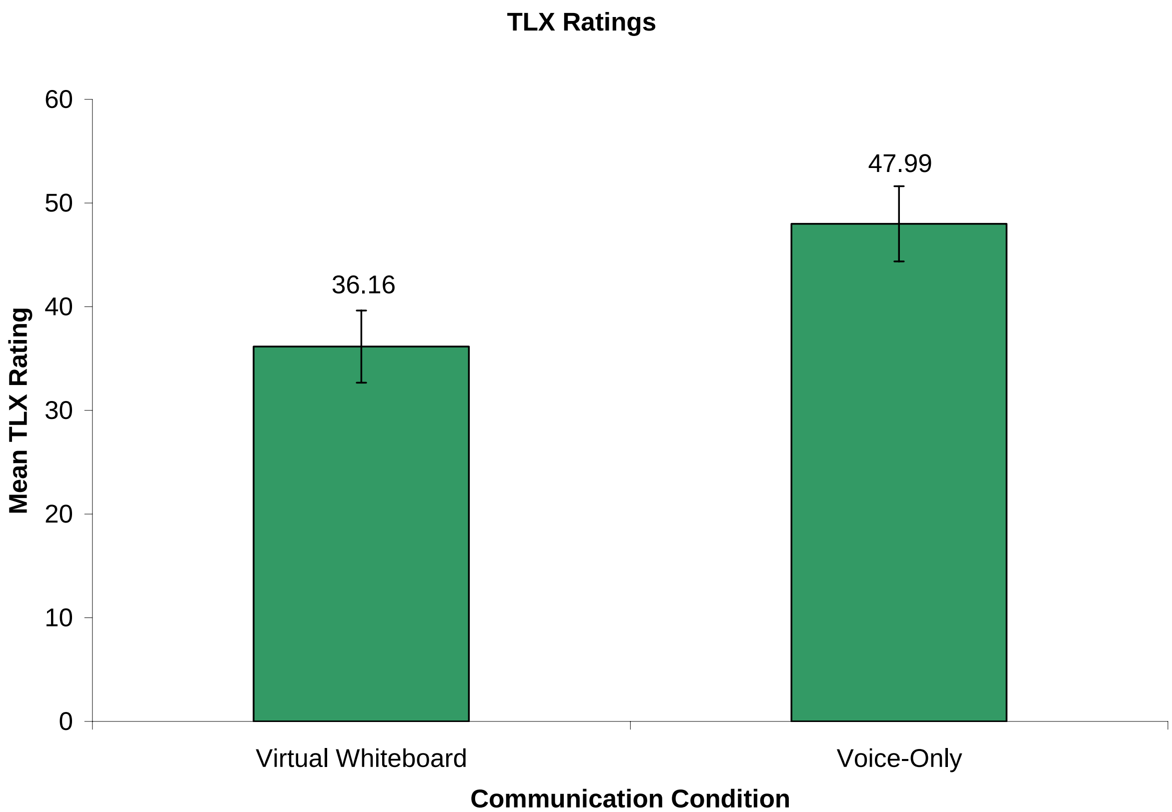

Figure 3. *Mean unweighted NASA-TLX ratings as a function of communication modality. Error bars represent one standard error of the mean in each direction.*

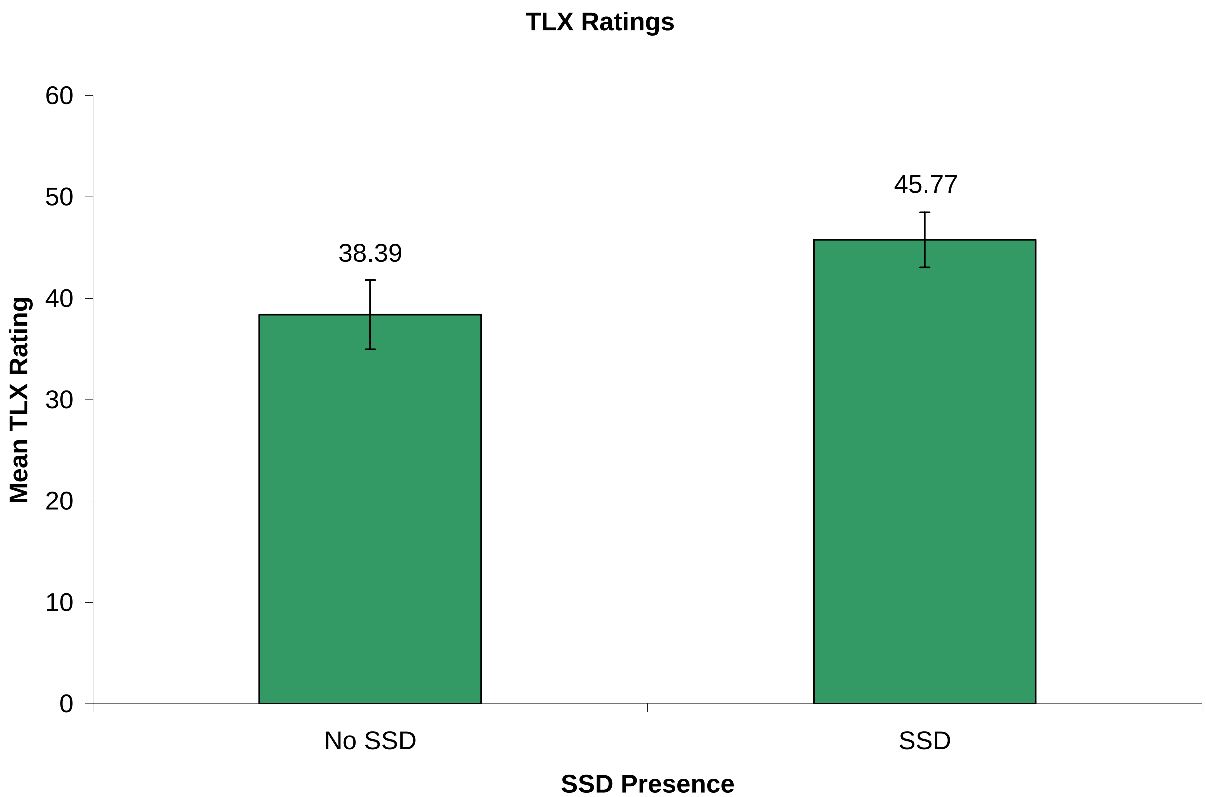

Figure 4. Mean unweighted NASA-TLX ratings as a function of SSD presence. Error bars represent one standard error of the mean in each direction.

Voice Communication

Communication frequency and duration were analysed to determine 1) if the utilization of a visual communication modality (i.e,. Virtual Whiteboard) reduced the demands of a voice channel, and 2) whether increased information availability (i.e., SSD) reduced the need for communication (e.g., language-based or visual).

Communication frequency was the number of radio transmissions between team members during the experimental trials. Analyses of communication frequency indicated a main effect for communication medium, $F(1, 7) = 68.09$, $p < .0001$, and presence of SSD, $F(1, 7) = 9.86$, $p < .05$ (see Figures 5 and 6). Analyses reveal that frequency of voice communication was reduced when teams could use the Virtual Whiteboard medium and when the SSD was present.

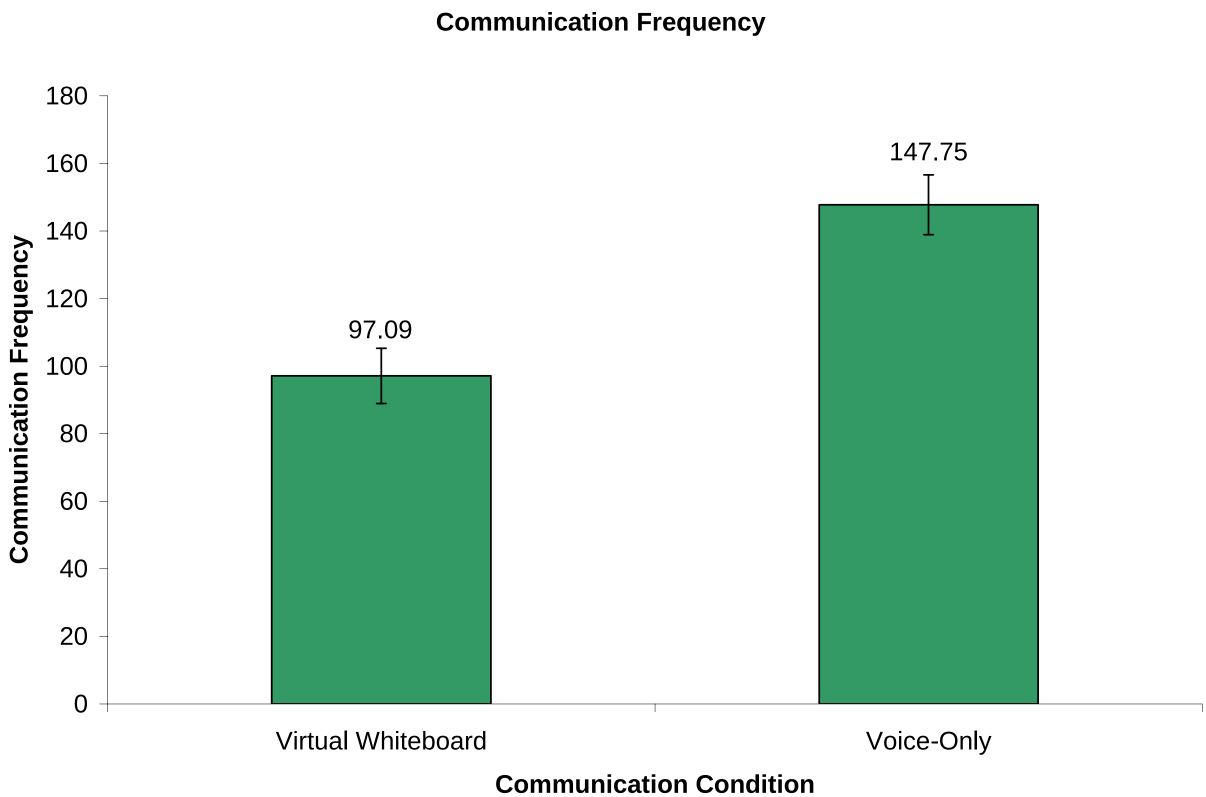

Figure 5. *The mean number of radio transmissions per experimental trial as a function of communication modality. Error bars represent one standard error of the mean in each direction.*

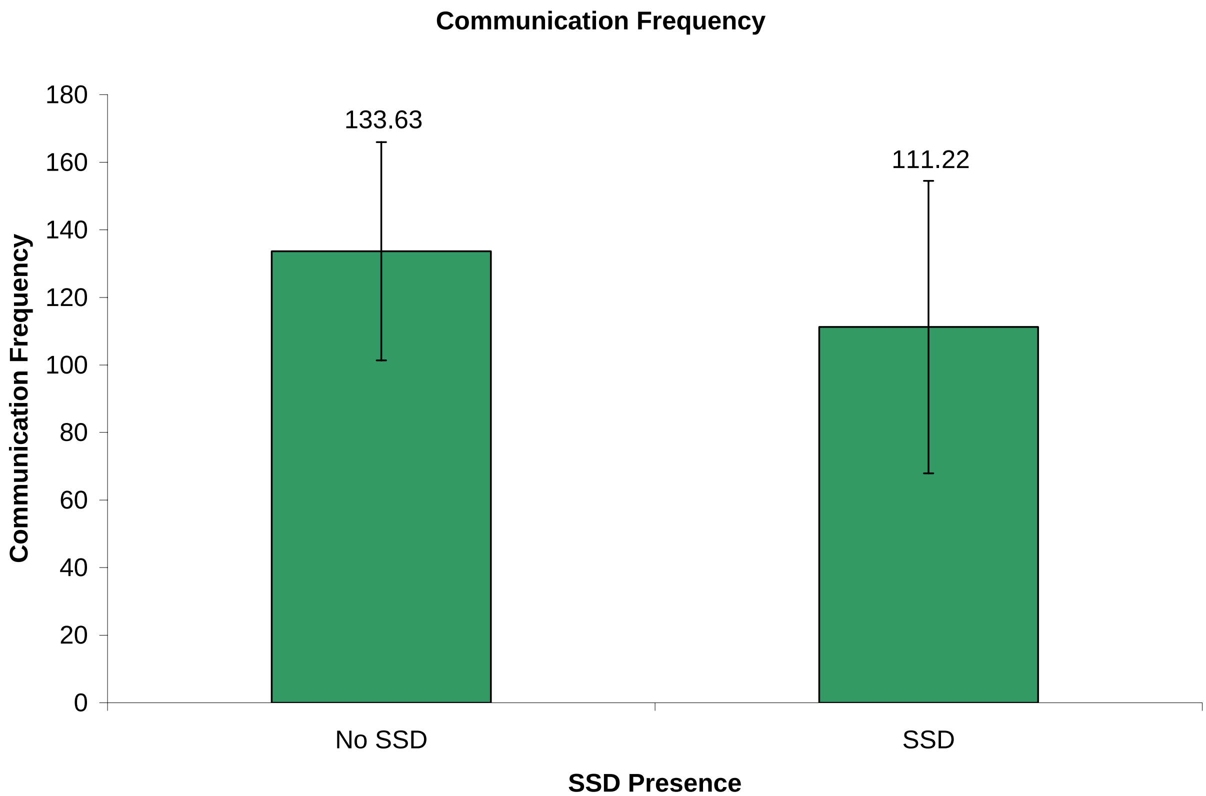

Figure 6. The mean number of radio transmissions per experimental trial as a function of communication modality. Error bars represent one standard error of the mean in each direction.

Communication duration was calculated as the total duration (in seconds) of voice communication over the radio for each 10-minute experimental trial. Analyses of communication duration indicated a main effect for communication medium, $F(1, 7) = 79.07$, $p < .0001$ (see Figure 7). Analyses reveal that duration of voice communication was reduced when teams could use the Virtual Whiteboard medium.

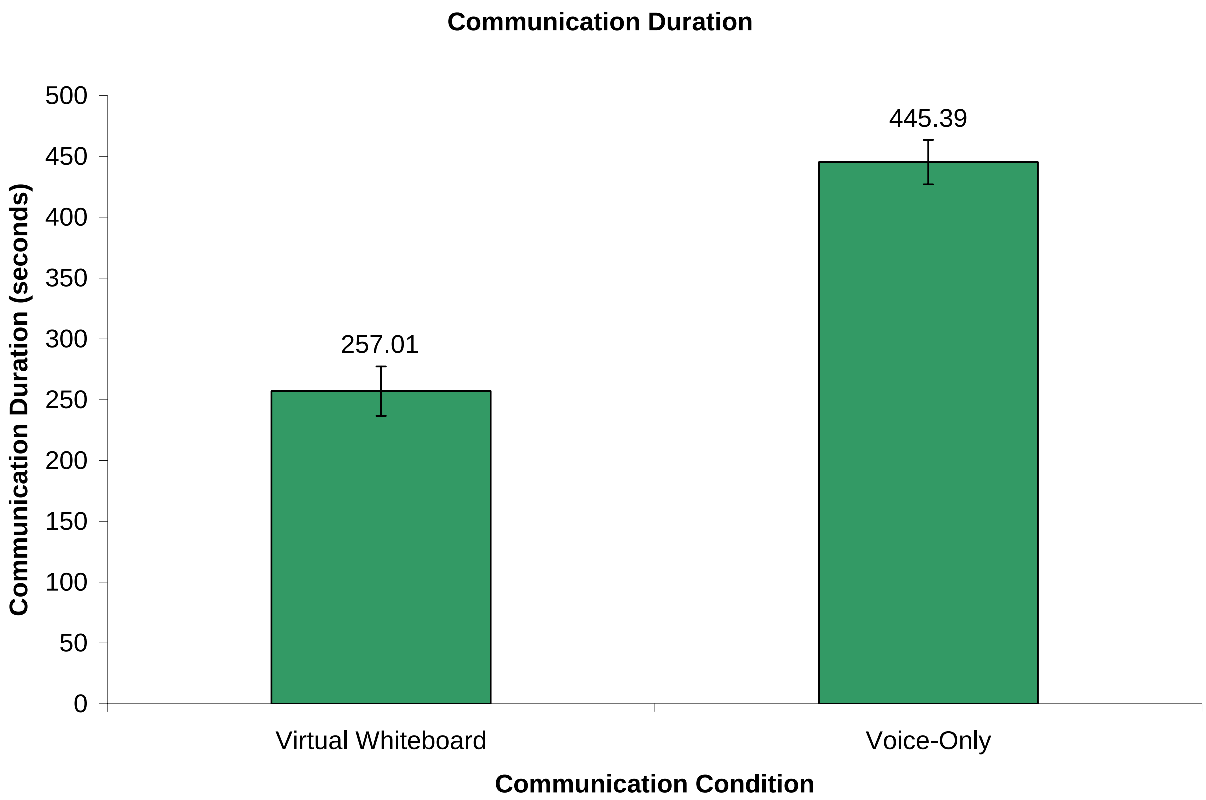

Figure 7. The mean duration of voice communication over the radio as a function of communication modality. Error bars represent one standard error of the mean in each direction.

Secondary Task

The secondary task (i.e., CRM) employed is indicative of the ‘chatter’ present over radio communication channels in the air battle management domain. Analyses of CRM performance indicate a significant interaction between communication medium and SSD presence $F(1, 14.8) = 4.80$, $p < .05$. Analyses reveal that the best CRM performance was achieved during Virtual Whiteboard conditions without the presence of the SSD whereas the worst CRM performance was achieved during Virtual Whiteboard conditions with the presence of the SSD (see Figure 8).

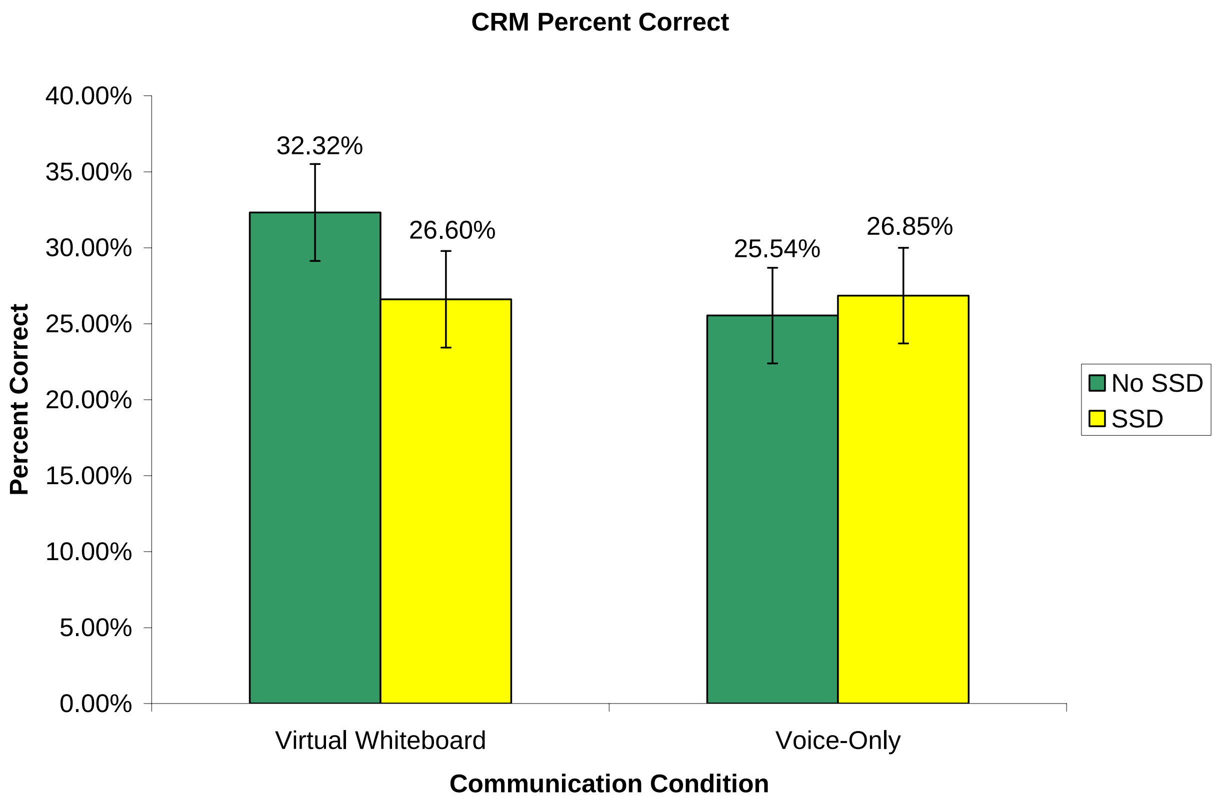

Figure 8. The Percentage of correct CRM responses as a function of communication medium and presence of the SSD. Error bars represent one standard error of the mean in each direction.

Discussion

The means through which communication is supported is an important part of dynamic decision-making and managing team interdependence (Rasmussen, Brehmer, & Leplat, 1991). Indeed, the demands of coordination within a complex C2 domain place constraints on the type of communication media utilized. Thus, within the AWACS BMC2 domain, teams must work through a dynamic and complex electronic battlefield wherein "…the time from detection to commitment may be measured in fractions of seconds" (Rochlin, 1996; p. 205). Therefore, within the AWACS BMC2 domain, effective collaborative systems must support rapid dissemination of relevant information. To be sure, AWACS BMC2 teams will adapt to the functional constraints of the work domain if those constraints are visible. Consequently, an effective communication medium must afford agents sufficient control of the complex AWACS domain by behaving like a window through which agents can share relevant knowledge (Flach & Bennett, 1996; Schwartz, Flach, Nelson, & Stokes, 2007).

According to semiotics, both visual and verbal communication can afford agents sufficient control of complex domains. Indeed, the dimensionality (e.g., visual vs. verbal) of communication that is most effective in revealing domain constraints may be informed by the specific tasks involved (Wainfan & Davis, 2004). Thus, for a complex domain, such as AWACS BMC2, wherein flexible communication is necessary in order to cope with dynamic situations, a multi-modal collaborative system can support teams and help ensure mission success.

Current literature on collaboration technologies focuses almost exclusively on mono-modal, language-based or verbal communication paradigms within business domains. However, the effectiveness of non-language based collaborative systems within C2 domains has been neglected. The purpose of this research was to determine the effectiveness of a non-language based visual collaborative tool (i.e., Virtual Whiteboard) within the AWACS BMC2 domain. Additionally, the effectiveness of a non-verbal status display system (i.e., Separable Status Display; SSD) was evaluated to determine how increased information availability impacted performance - whether the provision of more system-related information reduced the need for communication (e.g., language-based or visual); increase/decreased perceived workload; or increase/decrease mission-related performance.

Overall, results reveal that the Virtual Whiteboard tool improved the effectiveness of AWACS BMC2 teams. First, results indicated that using only voice (i.e., linguistic) communication resulted in higher subjective ratings of workload compared to voice communication augmented with visual communication (i.e., Virtual Whiteboard). The implications of this can be seen in the CRM results wherein performance was better using the Virtual Whiteboard tool. Presumably, subjects reported lower workload ratings during trials with the Virtual Whiteboard tool available because visual communication offset the linguistic communication demands (e.g., saturation) evidenced by the communication analysis. Specifically, when the Virtual Whiteboard tool was utilized, frequency and duration of communication was reduced. Second, results indicate that the Virtual Whiteboard tool reduced the amount of time each team spent prosecuting targets. Within the time-critical domain of air battle management, shedding seconds in the identification and prosecution of critical targets is a meaningful performance enhancement. To be sure, in a battle situation, the seconds exhausted prosecuting individual targets are compounded by the emergence of new potential targets. Thus, if the number of targets entering the area of responsibility (i.e., the screen) was not controlled (i.e., in this study, number of targets was controlled) there would have be a ‘build-up’ of targets during voice-only trials (i.e., in real-world scenarios). Furthermore, in real-world battle management domains, emerging situations can change dynamically within seconds. Thus, the ability of the WD to respond effectively within a very small window of time is critical.

Results were mixed for the SSD. On the negative side, presence of the SSD increased teams’ subjective workload ratings. However, presence of the SSD decreased the frequency and duration of communication. It can be argued that the latter effect occurred because the information made available by the SSD reduced the amount of information required over communication modalities (i.e., fuel and weapons status). However, as mentioned above in terms of net-centricity, information should be available to the right people, at the right time, in the right *form*. Perhaps, the increased perceived workload can be attributed to the latter aspect of net-centricity; that of form.

The status display employed in this study was a *separable* status display. According to Flach & Bennett (1992; also Pomerantz, 1986), there are three different types of displays – separable (separate elements for separate data variables), integral (high degree of interaction among elements; e.g., color is composite of hue and brightness), and configural (i.e., elements maintain separate status and interact to produce emergent features). Research conducted on separable and configural displays concludes that configural displays are better for integration tasks (where an agent must consider multiple elements/variables at once) and focused tasks

(considering each element/variable separately; Flach & Bennett, 1992). The key to configural displays is that they adequately specify the process domain that must be controlled – in other words, the semantics (or meaning) of the domain should be apparent. Thus, perhaps, the *form* of the information presented in the separable status display utilized in this study did not clearly specify the dimensions of system that needed to be controlled. Perceived workload ratings indicate that subjects experienced higher workload when they were required to make sense out of information presented in a separable display (as opposed to hearing relevant information through voice communication). Future research should consider the impact of a configural status display, wherein symmetrical geometric forms represent meaningful information.

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